UNIVERSITI PUTRA MALAYSIA

PROJECTING MODELS FOR RIVER CHANGES AND EVALUATION OF WATER QUALITY OF THE SAVANNAH RIVER NETWORKS

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FPAS 2021 3

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By

ALIYU GADDAFI ADAMU

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

December 2020

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

PROJECTING MODELS FOR RIVER CHANGES AND EVALUATION OF WATER QUALITY OF THE SAVANNAH RIVER NETWORKS

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Chairman : Associate Professor Nor Rohaizah Jamil, PhD
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This study seeks to project river Galma changes in the savannah region of Nigeria. The total area which was covered by water at River Galma has greatly decreased over years, which trigger more water pollution-associated issues in the area. The rapid landuse changes within the river basin has directly and indirectly caused long term implication towards the river quality degradation, therefore the Markov Chain Model (MC) and Cellular Automated Markov model (CA-Markov) used in this study will be useful in predicting future changes in the study area. The satellite image dataset of 2004, 2011 and 2018 was used in 2025-projection of river changes by incorporating both landuse changes pattern and water quality trends by adopting the MC and CA-Markov model. The hydrological factors which characterize the river responses were analysed with specific focus on the flow and water quality relationship, apart from the climatological influences towards this dam-regulated river system. A set of statistical tools, namely hierarchical cluster analysis (HCA), independent samples test (t-test), and Principal Component Analysis (PCA) was used on top of the standard water quality index (WQI) calculation to characterize the by-season and by-location variation of the water quality in the area. The shrinking pattern of water-covered area between the comparable satellite images in 7 years-interval period shows a decreasing trend in total water covered area (6.08 km^2 in 2004, 4.71km^2 in 2011, and 4.63 km^2 in 2018), and projected to further reduced in 2025 (4.39 km^2), which support by the decreasing trend in the river flow pattern over the tested dataset. The landuse prediction (surface total area changes) was made based on the dramatic changes of expanding agricultural-associated landuse type over that 14 years stretch of landuse changes trend, in exponential. The study area is considered as data-scarce in term of water quality, hence the prediction of future water quality status was made based on the complete one water cycle year from the fieldwork activities in 2018-2019. The WQI revealed the pollution increased in a downstream ward pattern in both wet and dry season, taking the downstream most sampling station (Sp. 15) as the most polluted section (WQI of 102.24 and 118.20 in

wet and dry season respectively). The upstream most sampling station (Sp.1), on contrary has better water quality status (62.74 and 75.14 in both wet and dry seasons respectively), which justify the landuse activities in the vicinity of the tested river section. T-test shows that nine (9) out of eighteen (18) water parameters were statistically significant ($p < 0.05$) in contributing the overall water quality status of the river for both tested seasons, with increased pollutant concentration values were observed during the dry seasons which can be directly linked to less rainfall-runoff interaction within the study area. The polluted most section (Sp.15) might have receiving direct contribution of pollutant-laden runoff from the nearby industrial and agricultural activities, besides the cumulative effects of the pollution from the upstream region at this downstream section. The upper section of the river basin was dominated by agricultural activities as the dominant landuse, hence can be associated directly with the significantly high concentration of agricultural-related pollutants such as nutrients load (magnesium, sulphate and phosphate). Different clusters were found during wet and dry season HACA classification analysis, with distinct and consistent pollution categories were discovered for Cluster 1 (Sp5, Sp6, Sp7 and Sp9 located middle of the river) and the remaining sampling points indicates difference in cluster 2, 3 and 4 in both tested season. To complement the HACA by-location pollution classification, the PCA was useful in determining the specific prominent pollutants that responsible in characterizing the overall state of water quality condition at polluted stations. The PCA suggests that 79.33% and 80.09% of the total variance in the variables from the respective wet and dry season samples can be directly associated with agriculture activities, with the turbidity, phosphate, magnesium, and Sulphate as the consistent pollutants type from both tested season. Similarly the LULC result show that for 14 years (2004 to 2018) the river decreases 1.45km^2, which signify a reduction in size from (6.08 km^2 to 4.63 km^2) at a declining rate of 0.104 per annum resulting from agriculture and human influence on the river. By this investigation, the results will provide a better understanding of the changes, spatial variation, and recent water quality status of the river in order to implement appropriate strategies to minimize changes and improve water quality management efforts in the river basin.

Thus, Projecting models of land use change, trend test, inferential statistics, WQI, environmetric multivariate statistical techniques, and mapping for environmental management should be employed in monitoring as they provide a detailed explanation in managing river resources, by making land use decisions that will preserve natural areas of River Galma watershed.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

MENGUNJURKAN MODEL PERUBAHAN SUNGAI DAN PENILAIAN KUALITI AIR RANGKAIAN SUNGAI SAVANNAH

Oleh

ALIYU GADDAFI ADAMU

Disember 2020

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Kajian ini bertujuan untuk menilai perubahan Sungai Galma di Wilayah Savana di Nigeria. Jumlah kawasan liputan air di Sungai Galma telah berkurang sejak bertahun-tahun, yang mencetuskan lebih banyak masalah berkaitan pencemaran air di daerah tersebut. Perubahan jenis guna tanah yang pesat di lembangan sungai secara langsung dan tidak langsung menyebabkan implikasi jangka panjang terhadap penurunan kualiti sungai, oleh itu Model Markov Chain (MC) dan model Markov Automated Cellular (CA-Markov) yang digunakan dalam kajian ini akan berguna dalam meramalkan pola perubahan masa depan di kawasan kajian. Set data imej satelit bagitahun 2004, 2011 dan 2018 digunakan dalam penganggaran bagi perubahan sungai pada tahun 2025 dengan menggabungkan kedua-dua corak perubahan guna tanah dan trend kualiti air, menggunapakai model MC dan CA-Markov. Faktor hidrologi yang mencirikan tindak balas sungai dianalisis dengan tumpuan khusus kepada hubungan aliran dan kualiti air, selain daripada pengaruh klimatologi bagi sungai yang diregulasi empangan ini. Satu set alat statistik iaitu analisis kluster hierarki (HCA), ujian sampel bebas (ujian-t), dan Analisis Komponen Utama (PCA) digunakan bagi pengiraan piawaian indeks kualiti air (WQI) untuk mencirikan variasi mengikut musim dan lokasi bagi kawasan kajian. Pola penyusutan kawasan liputan air di antara imej satelit yang dapat dibandingkan, bagi selang masa 7 tahun menunjukkan tren penurunan jumlah kawasan liputan air (6.08 km^2 pada tahun 2004, 4.71 km^2 pada tahun 2011, dan 4.63 km^2 pada tahun 2018), dan diunjurkan akan semakin berkurang pada tahun 2025 (4,39 km^2), yang turut disokong oleh trend penurunan aliran aliran sungai berbanding set data yang diuji. Ramalan penggunaan tanah (perubahan jumlah luas permukaan) dibuat berdasarkan perubahan dramatik dari peningkatan eksponensial jenis guna tanah berkaitan pertanian bagi tempoh 14 tahun tersebut.Kawasan kajian dianggap kekurangan data dari segi kualiti air, oleh itu ramalan status kualiti air masa depan dibuat berdasarkan satu tahun kitaran air yang lengkap iaitu berdasarkan cerapan data di lapangan pada 2018-2019. WQI mendedahkan pencemaran meningkat mengikut corak mengarah

ke hilir sungai pada musim hujan dan kering, menjadikan stesen persampelan paling hilir (Sp. 15) sebagai bahagian sungai paling tercemar (WQI masing-masing 102.24 dan 118.20 pada musim hujan dan kering). Stesen persampelan paling hulu (Sp.1), sebaliknya mempunyai status kualiti air yang lebih baik (bacaan WQI 62.74 dan 75.14 pada musim hujan dan kering masing-masing), yang membuktikan bahawa terdapat perkaitan langsung jenis aktiviti guna tanah di sekitar kawasan yang diuji.. Uji-t menunjukkan bahawa sembilan (9) daripada lapan belas (18) parameter air signifikan secara statistik ($p < 0,05$) dalam menyumbang status kualiti air sungai keseluruhannya untuk kedua-dua musim yang diuji, dengan peningkatan nilai kepekatan pencemar diperhatikan selama musim kering musim yang boleh dihubungkan secara langsung dengan interaksi hujan-air larian di kawasan kajian. Bahagian sungai paling tercemar (Sp.15) mungkin menerima sumbangan langsung dari air larian yang mengandungi bahan cemar daripada aktiviti perindustrian dan pertanian di kawasan berhampiran, selain turut menerima kesan kumulatif bahan cemar dari kawasan yang lebih hulu dari bahagian ini. Kawasan lembangan di bahagian hulu sungai didominasi dengan aktiviti pertanian, yang boleh dikaitkan secara terus dengan kepekatan tinggi bahan cemar berkaitan pertanian seperti beban nutrient (magnesium, sulfat dan fosfat). Kluster yang berbeza ditemui ketika analisis klasifikasi HACA musim hujan dan kering, dengan kategori pencemaran yang berbeza dan konsisten ditemui untuk Kluster 1(Sp5, Sp6, Sp7 dan Sp9 yang terletak di tengah sungai) dan titik sampel yang selebihnya menunjukkan perbezaan dalam kluster 2, 3 dan 4 di dalam kedua-dua musim yang diuji. Untuk melengkapkan klasifikasi pencemaran lokasi oleh HACA, PCA berguna dalam menentukan pencemaran tertentu yang bertanggungjawab dalam mencirikan keadaan keseluruhan kualiti air di stesen tercemar. PCA menunjukkan bahawa 79.33% dan 80.09% dari jumlah varians dalam pemboleh ubah dari sampel musim hujan dan kering masing-masing dapat dikaitkan secara langsung dengan aktiviti pertanian, kekeruhan, fosfat, magnesium, dan sulfat sebagai jenis pencemar yang konsisten dari kedua-dua musim yang diuji. Begitu juga hasil LULC menunjukkan bahawa selama 14 tahun (2004 hingga 2018) sungai menurun 1.45km^2, yang menandakan pengurangan ukuran dari (6.08 Km^2 hingga 4.63 Km^2) pada kadar penurunan 0.104 setahun hasil dari pertanian dan pengaruh manusia terhadap sungai. Dengan kajian ini, hasilnya akan memberikan pemahaman yang lebih baik mengenai perubahan, variasi spasial, dan status kualiti air sungai terkini untuk menerapkan strategi yang sesuai untuk meminimumkan perubahan dan meningkatkan usaha pengurusan kualiti air di lembah sungai.

Oleh itu, mengunjurkan model perubahan penggunaan tanah, ujian trend, statistik inferensi, WQI, teknik statistik multivarietrik persekitaran, dan pemetaan untuk pengurusan alam sekitar harus digunakan dalam pemantauan kerana mereka memberikan penjelasan terperinci dalam menguruskan sumber sungai, dengan membuat keputusan penggunaan tanah yang akan memelihara kawasan tadahan air semula jadi Sungai Galma.

ACKNOWLEDGEMENTS

First and foremost, my gratitude is to Almighty Allah, the most gracious and merciful for his blessing. Writing this dissertation was not an accomplishment of my own. Hence, I would like to express some sincere words of thanks to the people that were indispensable in the realization of this work.

I owe the greatest thanks to Associate Professor Dr Rohaizah Binti Jamil, my supervisor, for her continued support, guidance and everything she has done for me over the last three years. I would like to thank her for the constructive and stimulating discussions. I am most grateful for her belief in me, because, without it, this dissertation would never have become a reality. Associate Professor Dr Nor Rohaizah, it was a great honour to have had die opportunity to work with you, and I would really like to continue the co-operation in the years ahead.

Furthermore, I would like to express my sincere thanks to all members of the supervisory committee: Prof. Madya Dr Mohd Bakri bin Adam and Dr Zufarzaana Zulkeflee for their ideas, great insights and all help with this research. I am very lucky to have had such a strong committee to guide me along the way. Special thanks go towards the Universiti Putra Malaysia and Faculty of Forestry and Environment by to making this research possible.

I would like to express my special thanks of gratitude to Tertiary Education Trust Fund (TETFund) as well as Federal College of Education Zaria (FCE) who gave me the golden opportunity to do this wonderful thesis, which also helped me in doing a lot of research and I came to know about so many new things I am really thankful to them.

I acknowledge my father, Alhaji Adamu Aliyu Shika and my late mother, Hajiya Hafsatu Adamu for giving me the best training, legacy and policy that is, fear of Allah, education and honesty.

Finally, I am also indebted to my wife (Sadiya Salisu El-Masur) for her prayers, understanding and encouragement and my sons (Adamu Gaddafi, Muhammad Gaddafi and Ammar Gaddafi) and daughter (Fatima Gaddafi) and well-wishers such as Khalid Adamu, Zayyad Adamu, Abubakar Adamu Aiyu, Aisha Bashir, Yusuf Dabo and the rest.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date: 08 April 2021

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a	Anti-image correlation matrices
APHA	American Public Health Association
AICM	Anti-image correlation matrices
BOD5	Biochemical oxygen demand
CCME	Canadian Council of Ministers of the Environment
COD	Chemical oxygen demand
Ca^{+2}	Calcium
CA	Cellular Automata
Cl^{-}	Chloride
°C	Degree Celsius
DO	Dissolve oxygen
DS	Dry season
Eq	Equation
EC	Electrical conductivity
EVA	Equal variances assumed
EVNA	Equal variances not assumed
FA	Factor analysis
GIS	Geographic Information System
HCA	Hierarchical cluster analysis
KSWA	Kaduna State Water Authority
KMO-MSA	Kaiser Kaiser-Meyer-Olkin Measure of Sampling Adequacy
LTEV	Levene's Test for Equality of Variances
Max.	Maximum
MC	Markov Chain model
Mg^{+2}	Magnesium

Min.	Minimum
mg/L	milligrams per litre
MK	Mann–Kendall
NG	Nigerian standard
NIMET	Nigerian meteorological agency
NO_3^-	Nitrate
NO_2^-	Nitrite
PO_4^{3-}	Phosphate
pH	Power of hydrogen
PSU	Practical salinity unit
PCA	Principal component analysis
ppt	Parts per thousand
PCC	Post Classification Comparison
RGBDA	River Galma Basin Development Authority
Sal	Salinity
SD	Standard Deviation
S_i	Desirable limit
SO_4^{2-}	Sulfate
Sp	Sampling point
SPSS	Statistical Package for Social Sciences
S/m	Siemens per meter
T	Temperature
Turb.	Turbidity
TDS	Total dissolve solids
TSS	Total suspended solids
TS	Total solids

TTEM	T-test for Equality of Means
UPM	Universiti Putra Malaysia
WS	Wet season
WQI	Water Quality Index
WQS	Water Quality Status
WQP	water quality parameters
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water is of great importance to the economy, industrial, agricultural, and other overall human activities. Man-made pollutions threaten freshwater bodies all over the world, and river Physico-chemical parameters convey much about its quality and fitness to humans and living biota within it (Animesh and Saxena, 2011; Marimuthu and Rajendran, 2017). Freshwater bodies all over the world are constantly faced with pollution challenges, most of which are anthropogenic in nature. All forms of life and all human activities are dependent on water. Water resources are of great importance to plants, animals, human life, and the economy and are the main source of meeting the demand for drinking water for irrigation of lands and industries. Rivers are waterways of strategic importance for domestic, industrial, and agricultural purposes (Jain, 2009). In developing countries, most notably Nigeria, water pollution creates a primary challenge for sustainable water resources management, thus ensuring water quality must be an issue of scientific and public concern. Scientists and researchers have identified several threatened water quality factors. These include, but are not limited to, agricultural activities, habitat destruction, invasive species, and human population (Eruola et al., 2011; Mkoma and Mihayo, 2012; Defersha et al., 2012; Dessu et al., 2014). Several studies have shown that many freshwater bodies are continually being polluted due to human activities which influence changes in the hydrologic regime, water quality and biodiversity of water bodies (Patil et al., 2012; Dessu et al., 2014; Garabaa and Zielinski 2015). Large watersheds pose many challenges for monitoring and management of water quality, particularly in multinational basins, where the legislative framework and priorities for water resources management differs (Bloesch et al., 2012).

In the savannah area of Nigeria, River Galma is the main drainage channel in Zaria as other rivers and streams discharge and emptied into it, and is located on latitude 11.30N and longitude 7.40E (Nnaji et al., 2010). The river Galma catchment lies within the tropical wet and dry climatic zones, characterized by strong seasonality in rainfall and temperature distribution. The catchment area lies in the natural vegetation zone known as the northern guinea savannah. The zone is characterized by vegetation, but cultivation, grass burning, and grazing activities have greatly modified the natural vegetation cover and composition. The soil has been classified as leached ferruginous tropical soil developed on weathered regolith rich in fine-grain quartz and oligoclase (Nnaji et al., 2010). The major rural land use activities in the catchment area are farming and animal rearing.

River Galma serves as a source of water for irrigation, fishing, and other agricultural activities. With the establishment of Zaria Dam in 1975 (Nnaji et al., 2010), it also serves as the main source of drinking water to the Zaria community, supplies by Zaria waterworks after treatment. The major land use in the catchment areas is farming, involving vegetables, grains, and roots crops production during wet and dry seasons on both sides of the river banks. However, due to the flourishing of agricultural activities, increase urban growth coupled with excessive exploitation on the land use is constantly changing the water capacity of the basin, as well as poor monitoring plan, the river is now greatly threatened; which could be overwhelming, if no control measure is adopted (Yusuf et al., 2012). Farmers and individuals living within the study area have claimed that the area underwater cover of the River Galma has greatly reduced (Field survey, 2018). Hence, the need to project the future state of this river using projecting models and evaluate the water quality in the Savannah River networks.

A model is a representation of reality used to simulate a process, understand a situation, predict an outcome, or analyse a problem (Bajaj and Wrycza, 2009). Detecting past changes and predicting these kinds of changes in the future play a key role in decision making and long term planning. Modelling is the main tool for studying land use and land cover change (Liping et al., 2018). Predictive models of land-use change are important tools for managing environmental issues. Project modelling can be used to evaluate land-use systems and identify important factors that affect land-use decisions (Han et al., 2015).

Pianosi et al. (2016) attested that both mechanistic and empirical approaches are widely used in modelling land-use dynamics. The mechanistic approach assumes that factors underlying the process are known, and explicit functions are used to connect these independent factors with modelled variables (Tyler et al., 2015). In empirical models, future changes in land-use are extrapolations of past changes. In a purely empirical model, no ecological assumptions are built into the modelling processes, which are based on observations only. Transition models (also called Markov models) are the most common empirical models of land-use dynamics and are often used to predict expected future land-use (Eshetu et al., 2017).

United Nation Food and Agricultural Organization defined the terms “land use” and “land cover” as land use “is the total of all arrangements, activities, and inputs that people undertake in a certain land cover type.” In contrast, land cover “is the observed physical and biological cover of the earth’s land as water body, rocks, vegetation or man-made features” (UNFAO, 1997).

Moreover, land cover refers to the natural surface of the earth uninterrupted by human activities. It represents water body, vegetation, natural or man-made features, and every other visible evidence of land use, e.g., cultivated/uncultivated land, settlements etc., land use, on the other hand, refers to the use of land by humans. It is the alterations done to land cover as a result of human activities such as farming, road construction, and so on. However, land use is obviously determined by environmental factors such as soil characteristics, climate, topography, vegetation, and water body. Land use and land cover change studies have become key components for managing natural resources and monitoring environmental changes. Igbokwe (2008) argued that land cover and land use information should form part of the environmental data, which are kept in the form of inventories/infrastructures in many advanced and emerging economies. Most land-use change factors such as river fluctuation, increase or decrease in rainfall, water flooding, air pollution, urban sprawl, soil erosion, deforestation, occurs without clear and logical planning which results in serious environmental degradation with notable consequences globally.

The most popular methods in recent land use/ land cover literature are the cellular and agent-based models or a hybrid of the two (An et al., 2005; Breuer et al., 2006; Le et al., 2006; Yang and Zheng, 2014). Cellular models include both Cellular Automata (CA) and Markov Chain (MC) models. For CA, each field's future state depends on the transitions calculated from spatio-temporal neighbourhoods, whereas in MC models, the field's future state depends on transitions calculated from lagged state value probabilities (Mukund et al., 2012).

Markov process models are a class of probability used to study the evolution of system overtime. Transition probabilities are used to identify how a system evolves from one time period to the next. A Markov chain is the behaviour of the system over time, as described by the transition probabilities and probability of the system in various states (Bhagawat, 2011). Markov chain model analyses two qualitative land cover images from different dates and produces a transition matrix, transition area matrix and a set of conditional probability images. However, Cellular Automata Markov is a combined cellular automata Markov Chain land cover projection procedure that adds an element of spatial contiguity, as well as knowledge of likely spatial distribution of transitions to Markov change analysis (Junfeng et al., 2019).

Change detection analysis approaches can be broadly classified into post-classification change methods or pre-classification spectral change detection. (Wijesekara et al., 2014). Remote sensing (RS) is an important technology to acquire geospatial data, and it is increasingly being used to expand useful sources of information for a wide array of applications (Bhaskaran et al. 2010; Mahmoud et al. 2011). Classification of RS data by using spectral, spatial and textural methods individually or in combination has also increased their application for feature extraction and mapping over the last decades. Classification of RS data has become a very active research topic (Rimal, 2011). Land use/land cover (LULC) mapping and detection of change using remote sensing and GIS techniques are of paramount importance to planners, geographers, environmentalists, and policymakers, in fact to everybody who cares about sustainable human development. Importantly, Remote Sensing provides an efficient means of obtaining information on temporal trends and spatial distribution needed for understanding, modelling and projecting land-use change (Liping et al., 2018). According to Keshtkar et al. (2017), integrating Remote sensing and Geographic Information System provides a comprehensive source of accurate, objective, up-to-date, and timely information that is peculiar to the site of river operations. The monitoring tool has been essential, facilitating sound decision making and consequently better management and governance of the river sector.

Therefore, Markov Chain Model (MC) and Cellular Automata Markov model (CA-Markov) is utilized in this research work to project river Galma changes and to come out with recommending necessary steps to be taken into account by the local communities, the authority to manage and policymakers to sustainable management issues, by making land-use decisions that will preserve natural areas of River Galma watershed.

Mann–Kendall (MK) and the Sen's slope estimator trend test of 31 years monthly rainfall analysis of the study area is applied in this research to support the water quality data. Water Quality Index (WQI) is applied in this research work. WQI is a tool to measure water quality (Al-Janali et al., 2012). WQI is helpful for the selection of appropriate treatment technique to meet the concerned issues. Tyagi et al. (2013), State that WQI measures the amplitude, scope and frequency of water quality which produces a value to indicate the type of water. WQI is defined as the weight of chemical concentrations determining the quality of water. Normally, water quality is linked to water classes. These are quality classification levels of water that determines the stages water needs to attain before being supplied for uses the intended purposes (Haritash et al., 2016; Bora and Goswami 2017; Gor and Shah, 2014; Rajankar et al., 2013; Balan et al., 2012; Sharma and Kansal, 2011; Fulazzaky et al., 2010 and Samantray et al., 2009).

Horton's method is used globally in calculating the water quality index (WQI) and was adopted and applied in this research. Horton developed this method in 1965, and Researchers nowadays are still using the method with some modifications (Stambuk-Giljanovic, 1999; Mohebbi et al., 2013). Horton (1965) suggested that the numerous water quality data could be combined into an overall index. WQI is a well-known effective tool for examining water quality that handles a stable, simple, reproducible unit of measure and communicates information about water quality to policymakers and concerned citizens. Thus, it becomes an effective tool for the management and evaluation of surface water.

Also, to strengthen the water quality results, multivariate statistical analysis is applied in this research work. Multivariate statistical analysis also is known as the multivariate analysis is an advanced analysis that is rooted for the assessment of the environmental database (Juahir et al., 2010; Nasir et al., 2011; Zali et al., 2011; Dominick et al., 2012). Apart from that, multivariate analysis is also exhibited as a division of environmental analytical chemistry that requires multivariate statistical modelling and data treatment known as chemo-metric analysis (Simeonov et al., 2003; Brodnjak-Voncina et al., 2002; Felipe-Sotelo et al., 2004; Kowalkowski et al., 2006; Pere'-Trepat et al., 2006; Osman et al., 2009; Saim et al., 2009; Gazzaz et al., 2012; Retnam et al., 2013). This quantitative technique is suitable for all aspects of the social and natural environment, including projecting, mathematical modelling, data analysis and statistics (Juahir et al., 2010; Nasir et al., 2011). Multivariate analysis methods have been applied for the groupings of the river monitoring sites according to their similarity of responses to the water quality variables. These methods include Hierarchical cluster analysis (HCA) and mapping. HCA is a multivariate technique commonly used to group similar variables into clusters, where the variance within the groups is reduced to the minimum, and the variance between groups is increased (Einax et al., 1997; Osei et al., 2010; CCME, 2015). HCA has been applied to enhance spatial sampling policies by decreasing the number of sampling sites and analysis costs (Kannel et al., 2007; Dominick et al., 2012). Extracted clustering information can, therefore, be considered in reducing the number of sampling points without significant loss of information (Wang et al., 2014; Juahir et al., 2011). Again independent samples test (t-test) and Principal Component Analysis (PCA) were also used to reveal and interpret useful information from the data set obtained from the river, by comparing the means and identify the pollution sources to the river. Therefore, the overall aim of this research is to carry out projecting models for river changes and evaluation of water quality of the Savannah River networks for adequate planning and better management strategy of the river ecosystem.

1.2 Statement of the Research Problem

Research has proved that problems associated with environmental monitoring and control persist through the history of mankind (Arzu et al., 2016). The situation is aggravated in recent times due to man's increasing intervention on the environment; hence, there remain few landscapes and water bodies on the earth's surface that have not been significantly altered by human beings in some ways (Arzu et al., 2016). Likewise, Nature endowed man; since ages, with many natural resources for the nourishment of his socio-economic needs. Since these needs are ever-changing and ever on the increase, the resources are often at the risk of changes (Nwadialor, 2001 and Elizabeth, 2014).

River Galma is situated in Zaria with a population of 6,066,562 people as at 2006 (NPC 2006), and the river is the main drainage channel in Zaria as other rivers and streams discharge and emptied into it. It also serves as the main source of drinking water to Zaria community. The major land use in the catchment areas is farming, which includes cultivation for food production, irrigation agriculture, animal rearing and farming activities on both sides of the riverbank throughout the year. The River Galma is currently loaded with run-offs from agricultural and municipal activities of the surrounding communities along its course at various adjoining tributaries (Yusuf et al., 2012) and (Patrick et al., 2015). However, agricultural influence has been identified as a critical factor militating against the realization of these noble objectives. Due to booming agricultural activities, rapid urban growth coupled with inadequate planning, as well as poor monitoring strategy, the river is now greatly threatened; which could be devastating, if no control measure is adopted. The areas underwater cover at River Galma has greatly decreased (Yusuf et al., 2012 and Field survey, 2018). If the water decrease the pollution will increase. Hence, the need to forecast the future state of this river using projecting models and evaluate the water quality. This informed the decision of the researcher to project the future state of this river using projecting models and study the water quality of the river since theories advocate that if the river water decrease the pollution will increase. Development of projecting models for the river watershed and the study of water quality of the river will provide better information about the changes in River Galma and also will provide the opportunity for understanding the trends of changes in the river watershed and this study will provide initial insight for future research in the field..

1.3 Objectives of the Study

1.3.1 General Objectives

The aim of this research is to execute projecting models for river changes and evaluation of water quality of the Savannah River networks.

1.3.2 Specific objectives

To achieve the aim, the specific objectives are set:

i. to determine the land cover adjustments in river Galma watershed in 2004, 2011 and 2018 to assess the land usage and analysis of the hydrological pattern.
ii. to analyse the spatial and seasonal variation of the river's water quality.
iii. to prepare future river change for 2025 using the Markov Chain model and Cellular Automata Markov model.
iv. to detect potential sources of contaminant to the river.

1.4 Research Questions:

The study intends to answer the following questions:

i. What was the differences in size of the river in 2004, 2011, 2018, and what is the hydrological pattern?
ii. What is the spatial and seasonal variation of the river water quality?
iii. What will be the possible river change for 2025?
iv. What is the potential contributor to the pollutions?

1.5 Scope of the Study

This study is designed to cover river Galma Zaria, Kaduna state, Nigeria. The study will attempt to projecting models for river changes and evaluation of water quality of the Savannah River networks of river Galma Zaria in Nigeria using Remote Sensing and GIS alongside multivariate statistical techniques. Satellite imageries of 2004, 2011 and 2018 with the application of Markov Chain model and Cellular Automata Markov model were used for the projecting models for river changes, and this is because the year interval between the input data (2011 to 2018) is fourteen years and Markov Chain model and Cellular Automata Markov model has the capability to project based on the year's interval. Again, Mann–Kendall (MK) trend test of 31 years monthly rainfall and river discharge analysis of the study area is applied in this research to support the water quality data. Two sets of water samples were collected for the analyses during June 2018 and December 2018, distinct wet and dry seasons. Sampling sites were identified based on stratified random sampling techniques with the sole objective of obtaining representative water samples from the study area. Water samples were collected from fifteen sampling points along the river, and all the physicochemical parameters were determined using standard methods described by the American Public Health Association (APHA, 2018). All data generated were subjected to descriptive statistics using Microsoft Excel (minimum, maximum, tested means, and standard deviation of the river water quality parameters). Moreover, the data were subjected to a water quality index test using Horton's method computation with Nigeria or World Health Organization (WHO) standards in Microsoft Excel, Inferential statistic and Principal Component Analysis (PCA) using Statistical Package for Social Science (SPSS statistic 23) and Hierarchical Cluster Analysis (HCA) using Past3 and Mapping using ArcMap 10.2.2 respectively.

1.6 Significance of the Study

The earth comprises 71% water and 29% landmass (Williams, 2017). This implies that more than half of the earth is occupied by water, the majority of which is ocean/seawater than the running water in rivers. The issue now is that most of the rivers are being decreased, polluted, silted, and some even lost all as a result of agricultural activities, sand quarrying, rapid urban growth coupled with inadequate planning, as well as poor monitoring strategy, which could be a threat and disturbing at a point. Water is a resource that is both valuable and vital to the existence of all living organisms, but this valued resource is increasingly being threatened as human populations grow and demand more water of high ecosystem service. There is an increasing rate of water bodies reducing in Nigeria, especially in the Northern part of the country, and a constant cry of potable water scarcity, especially in Zaria as a whole, where when carefully managed, the river Galma could go a long way to silencing the cry. Presently Zaria as a whole, experience water scarcity problem and this community solely rely on the River Galma. This, therefore, calls for this research. At the end of this research, the Zaria community, Zaria waterworks, authorities, Federal Ministry of Health, Zaria Water Works as well as the Kaduna State Water Authority (KSWA) and other benefactors of this river will be able to ascertain the best way to curtail the river reduction, source of pollution to the river and to maintain good water quality status for the purpose of drinking, irrigations, aquatic animals and domestic activities.

1.7 Thesis outline

This thesis consists of five chapters. The chapters in this thesis have been organized and presented as follows:

Chapter 1 gives the background of the study, the research problem, research questions, general and specific objectives, scope of the study, justification of the study and thesis outline.

Chapter 2 is based on previous research, readings and findings, this chapter will discuss change detection, land use /cover change (LUCC) models, remote sensing and geographic information system, time series models and analysis, transition probability matrix, application of Markov chain model, application of cellular automata model, water quality, water quality index and multivariate statistical analysis. Relevant literature was reviewed under the following themes: application of Markov chain models and cellular automata models and application of multivariate statistical analysis in water quality studies.

Chapter 3 discusses the detailed description of the study area and the methodology of the research. The chapter contains the study area, methodology, data sources, instrumentation, data collection procedure, image processing, Markov chain model and Cellular Automata Markov model Processes, trend analysis of Mann–Kendall and Sen slope estimator, multivariate statistical techniques and methods of data analysis. Characteristics and data of the study area were also summarized.

Chapter 4 contains the result, findings and discussion of the research. The chapter discusses results obtained from the extent of river Galma in 2004, 2011, 2018 and hydrological trend analysis. River projection for 2025 was made, using a Markov chain model and Cellular Automata Markov model. Results are represented using tables, maps and charts. Also, the chapter presents the result of the In-situ and laboratory analysis carried out using the collected water samples. The result is presented in a tabular and figure forms, then followed by a discussion according to the parameters analysed or checked for in the field and laboratory. The chapter also presents the spatial and seasonal variation of the river water quality, detect the possible pollution sources to the river.

Lastly, Chapter 5 presents the summary, conclusion and recommendation based on findings of the study.

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LIST OF PUBLICATIONS

Aliyu G.A., Jamil N.R.B., Adam M.B. and Zulkeflee Z. (2019). Assessment of Guinea Savanna River system to evaluate water quality and water monitoring networks. Published by *Global J Environ Sci Manage* 5(3). https://doi.org/10.22034/gjesm.2019.03.0.

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